Characterization of Uncertainty in Low Frequency Active Sonar

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LONG-TERM GOALS

The goals of this project are to characterize and evaluate the effects of uncertainty on low frequency impulsive active sonars of the type exemplified by Distant Thunder (DT) or Extended Echo Ranging (EER). This project is a component of the UNITES effort aimed at (i) comprehending uncertainty in the ocean environment and characterizing its impact on tactical sonar performance, and (ii) providing the Navy with guidance for understanding sonar performance in the littoral.

OBJECTIVES

Performance prediction models are used to characterize expected operational capabilities of sonars. The signal-to-interference ratio (SIR) environmentally-induced probability density function (SIRE-PDF) is the distribution of the difference between measured and modeled SIR, and describes the predictive capability of the present model (that is, for specific location and time) with respect to actual performance. Thus, the SIRE-PDF accounts for the inherent unmodeled variability of the environment and is a probabilistic description of intrinsic environmental uncertainty. The focus of this effort is to formulate and evaluate significant examples of SIRE-PDF for low frequency impulsive active sonars

APPROACH

To establish the interference component of the SIRE-PDF, a data-based approach will be followed using environmentally well characterized reverberation and noise data selected from the Area Characterization Test III (ACT III) obtained under the DARPA Adverse Environments program in 1996 and from SHAREM 126 under the NAVSEA MAASW(DT) program in 1998 in operationally significant areas (Korea Strait in '96 and East China Sea in '98). These data will be used to determine the distribution of the difference between measured and modeled reverberation or noise interference. To establish the signal component of the SIRE-PDF selected high signal-to-background target echoes from DT exercises (SHAREM 122, 126, 127, 130 and 136) since 1997 will be used. These data will be used to determine the distribution of the difference between measured and modeled target strength. The signal-to-interference EPDF can be constructed from the distributions of measured minus modeled signal and interference [1].

The initial work has focused on characterization of interference, i.e., reverberation and noise, with particular emphasis on reverberation for active sonar characterization. Reverberation modeling uncertainty involves stochastic variability of reverberation scattering strength and of transmission loss to and from the scattering region, plus more systematic uncertainty involving spatial variations of scattering strength and transmission factor. These spatial variations can occur over range, azimuth,

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14. ABSTRACT

The goals of this project are to characterize and evaluate the effects of uncertainty on low frequency impulsive active sonars of the type exemplified by Distant Thunder (DT) or Extended Echo Ranging (EER). This project is a component of the UNITES effort aimed at (i) comprehending uncertainty in the ocean environment and characterizing its impact on tactical sonar performance, and (ii) providing the Navy with guidance for understanding sonar performance in the littoral.

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distance from the shore in continental shelf areas and source and/or receiver depth. Characteristically, for shallow water active sonar, bottom reverberation is the prevalent interference. The uncertainties under consideration are manifest in bottom scattering strength measurements. Recent bottom scattering strength determinations [2] suggest a typical statistical variability in the determination of scattering strength of ±3-4 dB, with this uncertainty dominated by the variability in the transmission loss. To determine the interference SIRE-PDF, reverberation modeling can be accomplished using measurement-derived scattering strengths with appropriate propagation codes incorporating the most reliable geo-acoustic models. By further analyzing the reverberation data collected under the Adverse Environments program [2] and other experiments the distribution of the difference between measured and modeled reverberation (reflecting the sources of variability described above) will be obtained. Selection of the data for analysis and definition of the procedure is under the direction of Peter Cable (BBN); data processing is under the direction of Jay Pulli (BBN) and has been performed by Zach Upton and Kathi Fuqua of BBN. The direction and results of the analysis process are closely coordinated with the work at OASIS, our colleagues in this effort, for further analysis under the direction of Philip Abbot.

WORK COMPLETED

Initial data processing and editing were performed for ACT III and SHAREM 126 data sets. For archived Area Characterization Test III (ACT III) data, hydrophone level reverberation and noise recordings from a bottomed receiving array in Korea Strait were reviewed and selected after the ACT III test plan and reconstruction data base had been studied to find the most appropriate data segments. The selected data were written to disk storage files in MATLAB format for processing and analysis, a process requiring the writing and application of a new utility program because the original storage media employed formats no longer in use in the BBN data analysis laboratory. Appropriate SHAREM 126 (from the East China Sea) beam level data snippets (data that included passive reflector echoes and reverberation) were also selected and read into files in MATLAB format for future processing.

Both reverberation and noise data statistics were computed. The analysis procedure for the reverberation computations is described; the noise analysis closely parallels. For the reverberation analysis an experimental ensemble of bottom scattering strength estimates were computed from the data for both the ACT III data and for the SHAREM 126 data (this process assumes spatial isotropy and homogeneity of the scattering process, and care was taken to satisfy the experimental conditions for spatial stationarity). The analysis procedures invoked in the determination of scattering strength for the two data sets are different: for the ACT III data the procedure involves adjusting for the two-way transmission loss from source to scattering area to receiver and by accounting for the size of the bottom region contributing to the reverberation at any time after the source transmission; for the SHAREM 126 data, scattering strength was determined by direct comparison of reverberation and (calibrated) reflector echo levels after correction for the area contributing to the reverberation. To detrend the ACT III data for transmission effects, the reduced transmission factors obtained from ACT III transmission data, derived from a linear regression analysis after removal of cylindrical spreading, results in determination of the slope of reduced transmission loss vs range (attenuation factor [dB/km]) and ordinate intercept (limit of spherical spreading [dB//km^2]) [3]. Scattering strengths were then determined in octave bands centered at 75, 150, 300 and 600 Hz using the method in [2] for data averaging (via time integration) to yield 1, 2, 5 and 10 degrees of freedom per estimate. Statistics of bottom scattering strength estimates were examined by using measurement ensembles comprised of 15 s data records from the 30 independent hydrophone channels. Statistics for the SHAREM 126 data are still being investigated.

RESULTS

Probability density functions for ambient noise level estimates and for bottom scattering strength estimates have been obtained the ACT III Korea Strait data. Figure 1 shows EPDFs for the instantaneous (time-bandwidth product of one) scattering strength determinations obtained from low frequency impulsive source reverberation data from Korea Strait. These statistics establish the amount of echo fluctuation associated with reverberation interference in a low frequency active sonar operating in this area. As anticipated for a Gaussian process, the instantaneous diffuse reverberation exhibits a constant standard deviation that is independent of the derived scattering strength mean. For the Korea Strait data the standard deviation associated with the instantaneous diffuse reverberation is about 3.8 dB. As processing integration time is increased (time-bandwidth product greater than one), the standard deviation of scattering strength and level estimates decrease (decreasing as 4.34 sqrt[1/μ] for time-bandwidth product = μ » 1). This behavior is indicated in Figure 2 for Korea Strait 300 Hz noise statistics.

IMPACT/APPLICATIONS

There is a Fleet concern that performance prediction and tactical decision aids (TDA) are often not reliable because of the inherent uncertainty associated with the TDA inputs. The impact of the current work will be to identify the sources of uncertainty (whether from intrinsic variability or unknown end-to-end parameters) for low frequency broadband active sonars and to reduce, to the extent possible, the unknown to intrinsic variability. The application will be to TDA improvements for such systems as DT and IEER.

TRANSITIONS

There are no transitions yet, but the results of these studies, the SRI-PDFs for low frequency broadband active sonar will be used by our UNITES colleague Philip Abbot at OASIS in his investigation.

RELATED PROJECTS

This project is part of the UNITES project and is coordinated and linked with the other efforts under the UNITES team. Other related projects include the other programs under the ONR Code 32 Department Research Initiative (DRI) on the effect of acoustic environmental uncertainty on the performance of Navy systems. Reference to this program and these projects can be found at the following website: http://www.onr.navy.mil/sci_tech/chief/cuwg/default.htm

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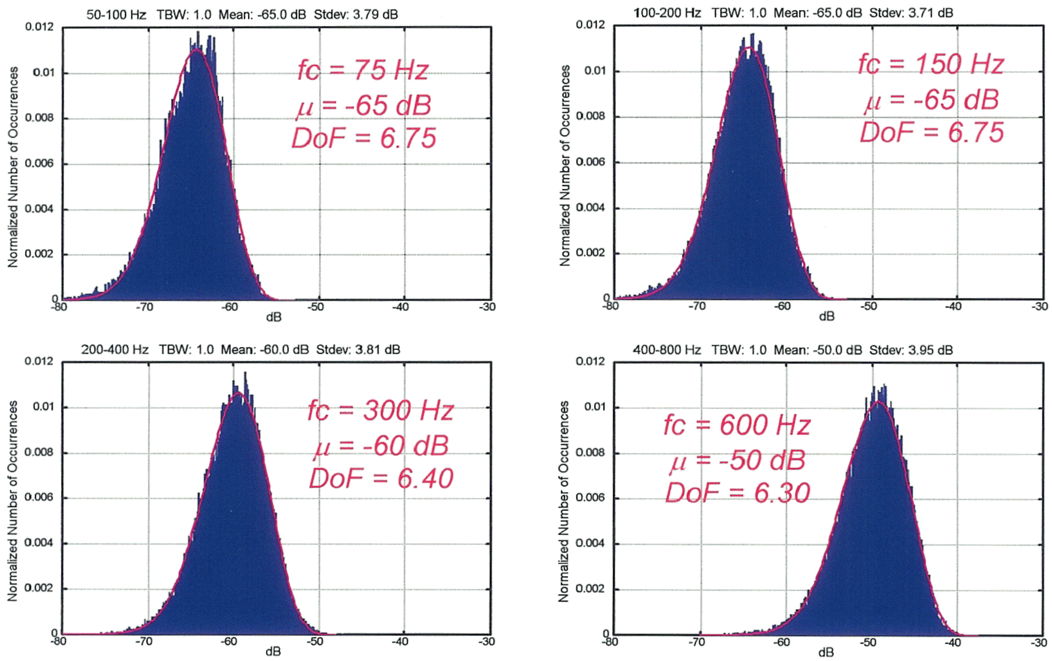

Figure 1. EPDFs for instantaneous (i.e., time-bandwidth product of one) bottom scattering strength estimates from Korea Strait for octave bands centered at 75, 150, 300 and 600 Hz. The standard deviation of each estimate is about 3.8 dB.

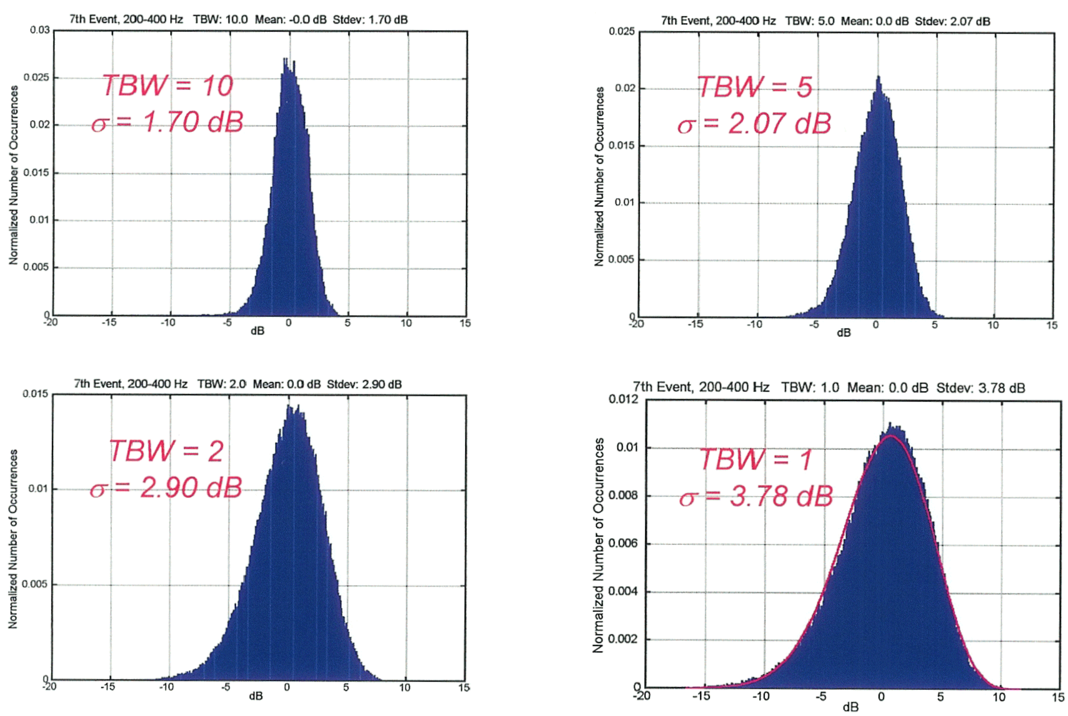

Figure 2. EPDFs for estimates of noise level at 300 Hz in Korea Strait for time-bandwidth products of 1, 2, 5 and 10. The corresponding standard deviations are 3.78 dB, 2.90 dB, 2.07 dB and 2.90 dB.